Recent GATE developments at Medical University of Vienna

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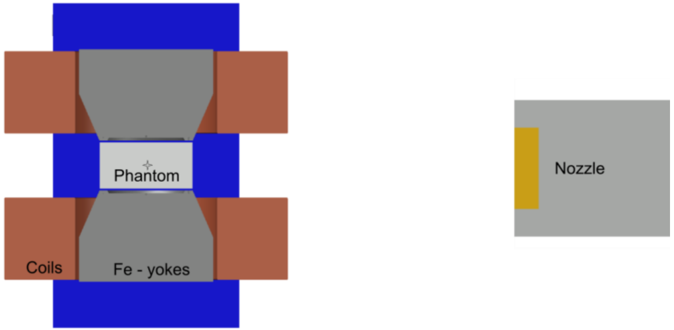
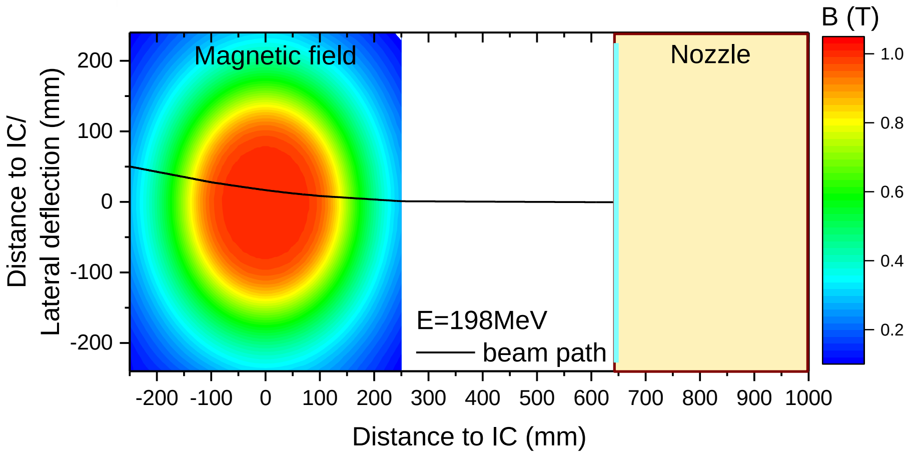
GATE/Geant 4 model

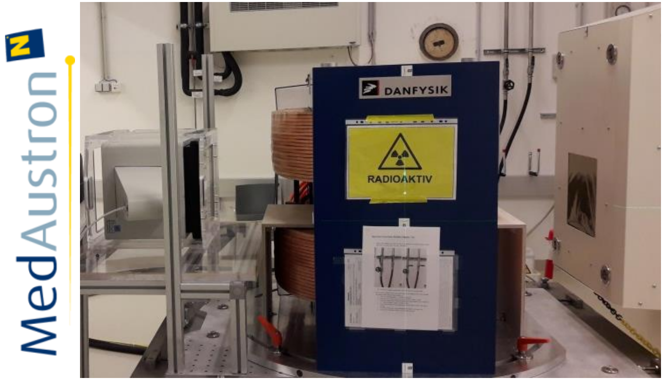
- Clinical proton beam line
  - E = 62.4 - 252.7 MeV
- Magnet (B = 0-1T)
- Developer version
  - GEANT4.10.03.p03
  - GATE8.0
  - Custom 3D Magnetic field maps implementation

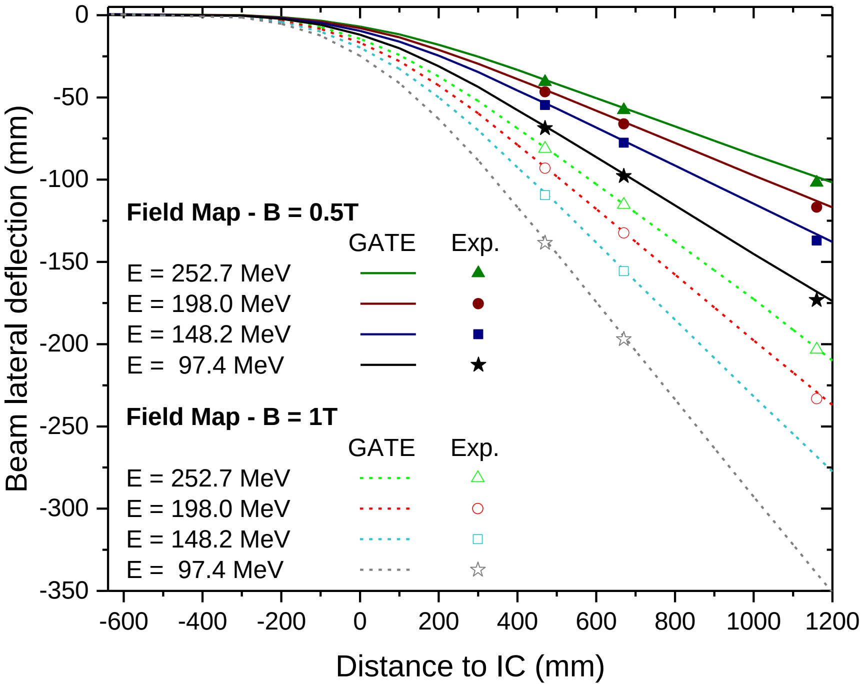




Experimental benchmarking @ MedAustron

- Deflection of proton beams benchmarked at 3 distances from isocenter
  - Measured with Lynx
  - Simulated with Gate





EnergySpectrumActor

- Energy spectrum
  - Fluence

$$\Phi_t(E) = \frac{\sum_i^V s_i}{V}(E)$$

  - Energy deposition

$$Edep(E) = \Phi_t(E)S(E)$$

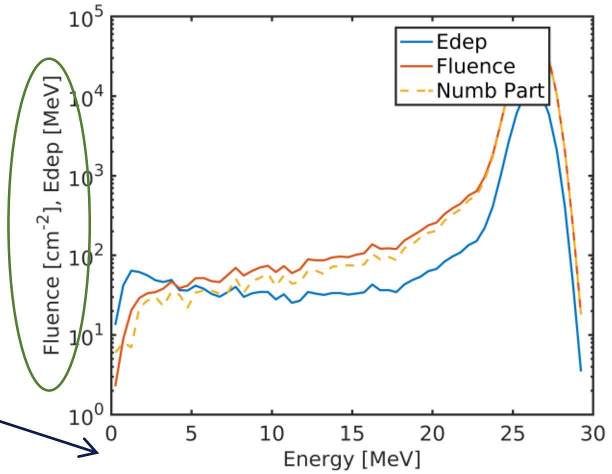
  - Number of particles

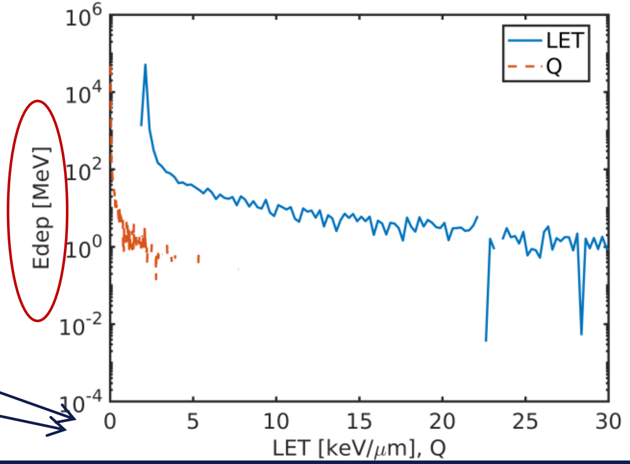
- LET spectrum

$$Edep(LET) = Edep(S_{el})$$

- Q spectrum

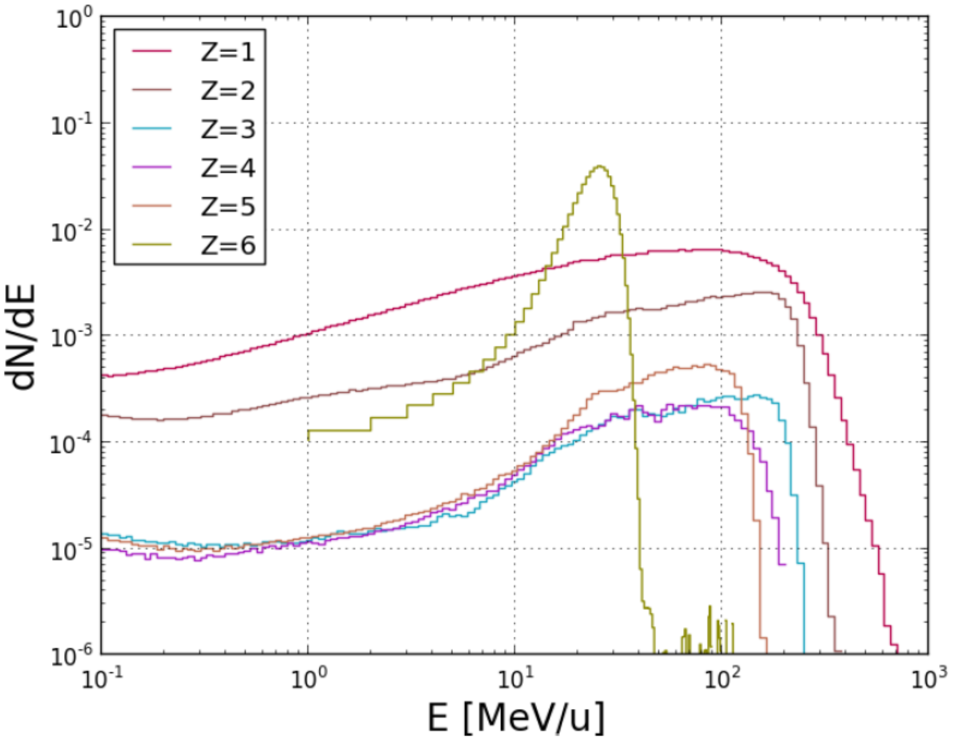
$Edep(Q) = Edep(\frac{Z^2}{E})$ …. see Lühr et al. 2017





EnergySpectrumActor

- Options
  - Logarithmic energy binning
  - Normalization to primary particles
  - Energy per unit mass [MeV/u] or total [MeV]



300 MeV/u C12 ion beam at 17 cm in water

EnergySpectrumActor – Fluence

- Implementation Fluence:

$$\Phi_t = \frac{\sum_i^V s_i}{V}$$

s_i… steplength

V… Volume

➔ Sum over all steps in volume

Papiez and Battista 1994

- Approximation

$$\Phi_c = \sum_i^A \frac{1}{\cos(\theta_i)}$$

θ_i… particles angle entering volume

A… cross plane

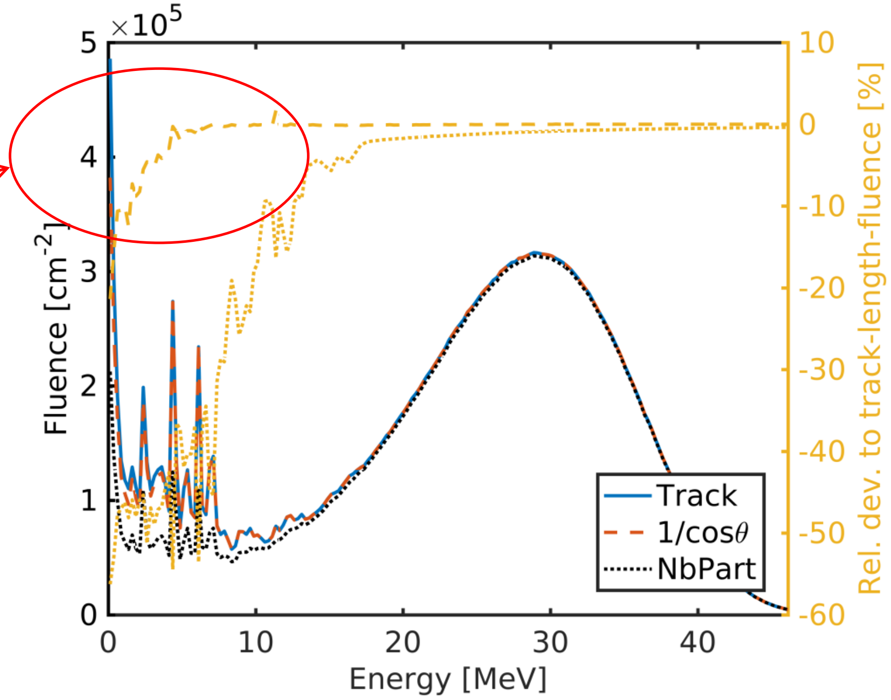
- ➔ Sum over all particles crossing the volume boundary
- How to handle singularities: $\cos(\theta_i)$ → 0 ?
- Assumes straight line path through voxel
  - Zick-zack path for low energy
  - Particles stopping within voxel

Default in Gate

Used for validation

EnergySpectrumActor – Fluence Validation

- Approximation
  - $\Phi_c = \sum_i^A \frac{1}{\cos(\theta_i)}$
  - Underestimation at low energy
    - → True path length higher than straight line approximation
    - → Singularities
- Number of particles
  - Assumes $\theta_i \approx 0$
  - Sufficiently accurate for high energies only



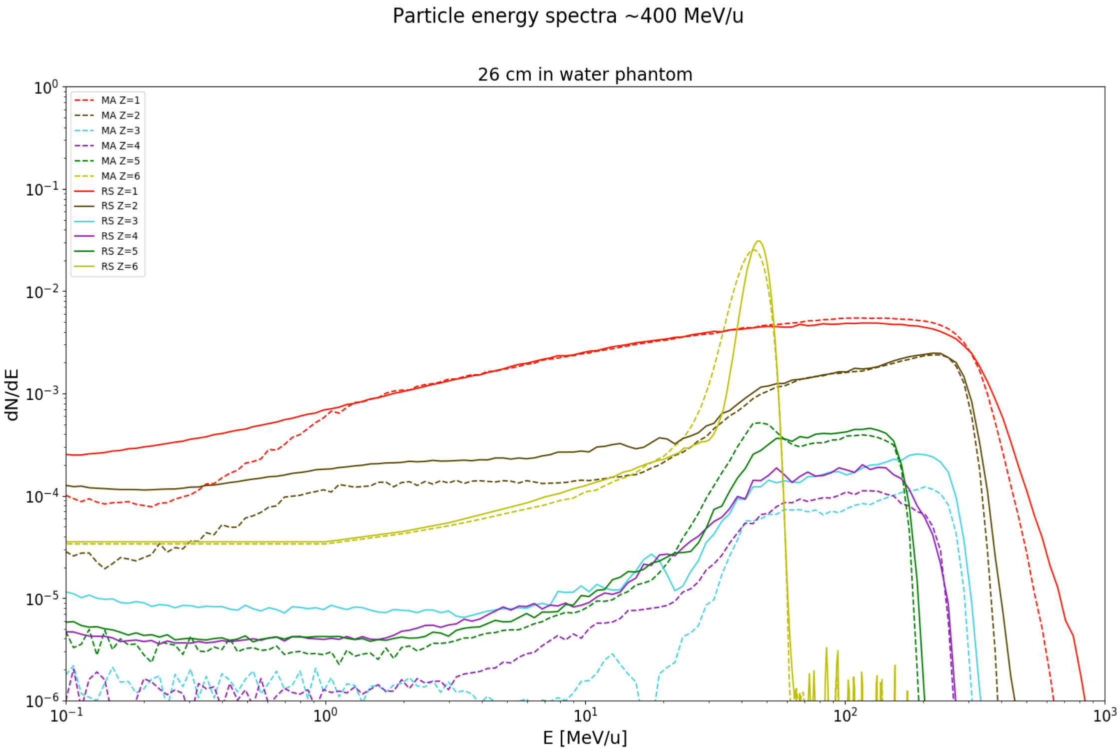
^{12}C ion beam energy spectra: Fluka vs Gate/G4

Main differences

- Low energetic region (<1MeV/u)
- Higher energy spread of primary carbons
- Less Lithium and Beryllium
- Lower maximum energy of secondary fragments in GATE

➔2 Beam models created with

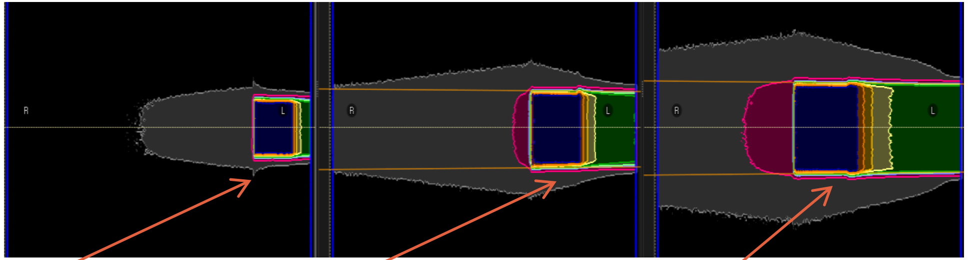
  - Fluka (clinical)
  - Gate / Geant4.10.03 (optional)



^{12}C Fragment spectra in treatment planning system: Fluka vs. Gate

- Evaluation of RBE weighted dose: $D_{RBE} = RBE\ D$

- Only minor deviations in the fragmentation tail
  - In 3 boxes centered at different depths in water
  - In clinical cases: 3 skull base chordomas



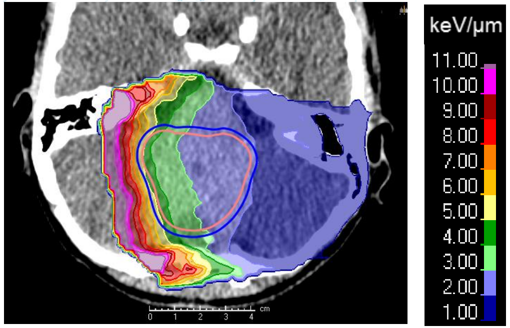
	Box 6	Box 8	Box 10
Plateau	0.4 % ± 0.3 %	0.2 % ± 0.2 %	0.1 % ± 0.2 %
Target	0.7 % ± 0.7 %	0.3 % ± 0.3 %	0.1 % ± 0.2 %
Fragmentation tail	-3.0 % ± 2.2 %	-3.3 % ± 2.6 %	-4.6 % ± 1.5 %

LET Actor: Dose and fluence average LET

$$LET_T(z) = \frac{\int_0^\infty S_{el}(E)\Phi(E,z)dE}{\int_0^\infty \Phi(E,z)dE}$$

$$LET_D(z) = \frac{\int_0^\infty S_{el}^2(E)\Phi(E,z)dE}{\int_0^\infty S_{el}\Phi(E,z)dE}$$

$S_{el} \ldots$ electronic stopping power



- Aim:

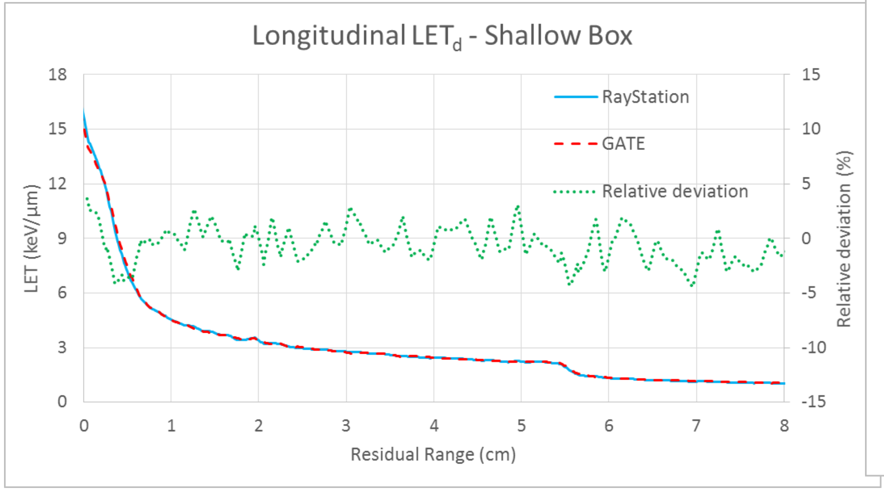
  Use $\mathrm{LET_d}$ distributions to evaluate different optimization strategies for cases with critical beam incidences

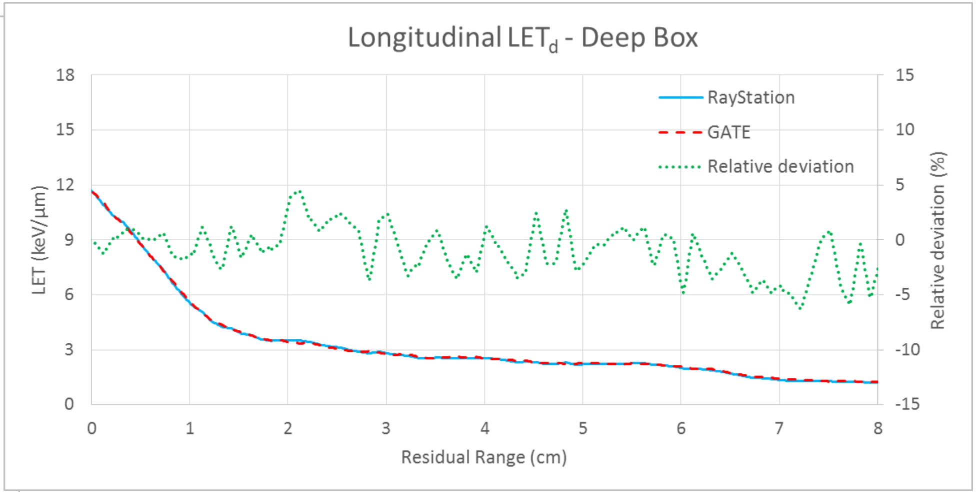
- Required step:

  Benchmark RayStation $\mathrm{LET_d}$ calculation against Gate/Geant4

  ➔ Using default option in Gate: 'Method C' from Cortes-Giraldo and Carabe 2015

LETd Validation RS – vs Gate/G4

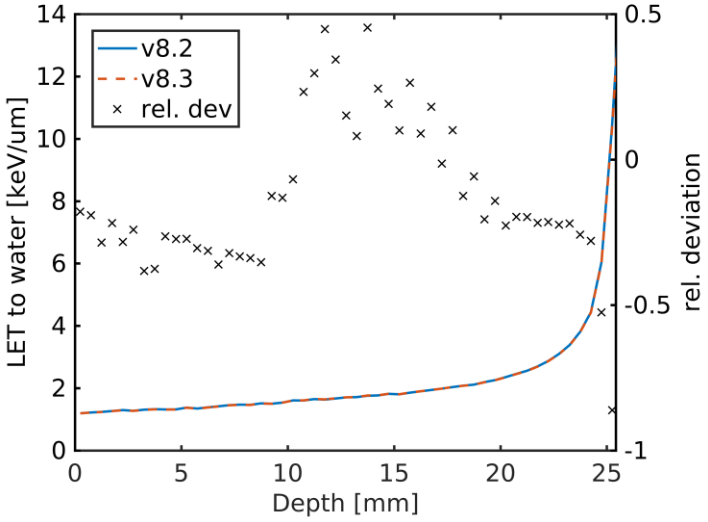




- Deviations within 5% mostly statistical noise
- Systematic deviation in the high gradient region

LETActor: Developments

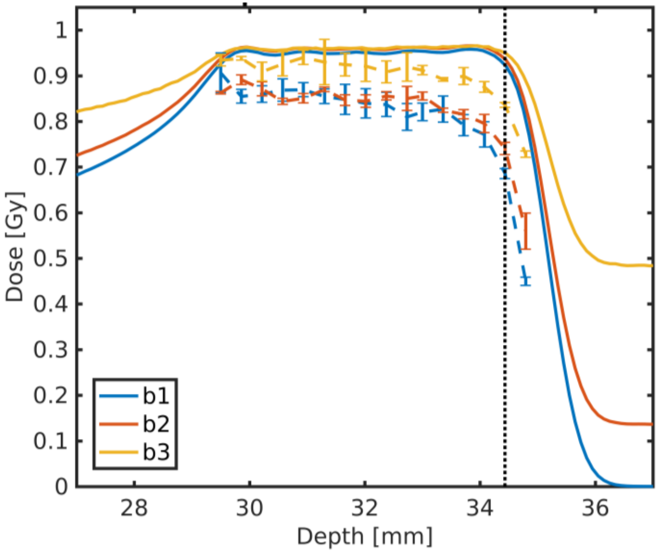
- Code improvements in v8.3
  - LET to water
  - Particle weight accounted in all scoring routines
- New in v8.3
  - Step Hit Type
    - → Can be chosen by user
    - → Default changed from Post to Random
  - Beam Quality Correction factors for films



62 MeV beam in PMMA

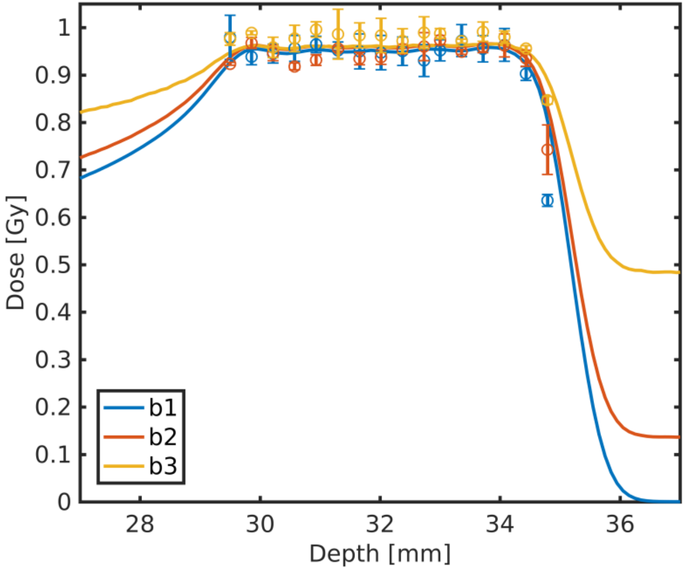
LET quenching in Gafchromic EBT3 films

Uncorrected film dose



Underresponse up to 20% in proton beams

Corrected film dose



Agreement within accuracy after correction

…publication almost submitted: Resch et al. 201?

EBT3 beam quality correction

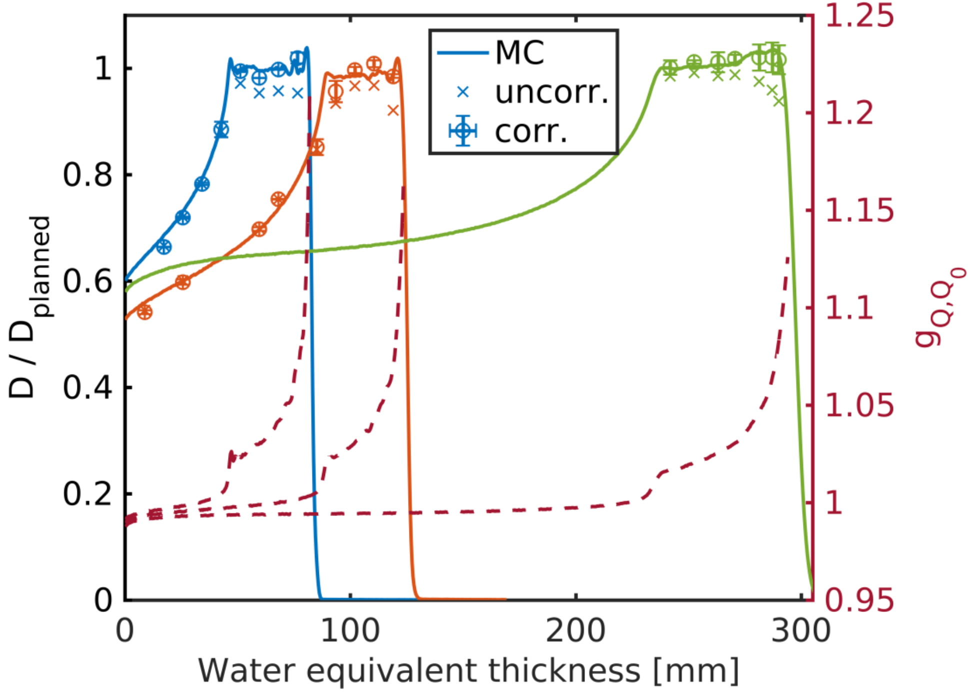
- Beam Quality correction factor g_{Q,Q_0} implemented into LET actor

$$D_{corr} = D_{film}\, g_{Q,Q_0}$$

$$g_{Q,Q_0} = a + b\, LET_d^{water}$$

  - No user knowledge or post-processing required
  - Material independent
  - For proton beams

- Available in develop branch



Summary and Conclusions

- Experimental validation of magnetic field maps
- Energy spectra
  - Fluence scoring implemented and validated for 12C and proton beams
- LET Actor
  - Code improvements
  - Raystation LET_d and LET_t calculation benchmark
  - Beam quality correction factors for EBT3 film dosimetry

Thank you for your attention

http://www.meduniwien.ac.at/hp/radonc/

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